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First record of a non-paleotropical intejocerid cephalopod from Darriwilian (Middle Ordovician) strata of central Spain

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Running Header: peri-Gondwana intejocerid

Abstract.—The order Intejocerida is an enigmatic, short lived cephalopod taxon, known previously only from Early–Middle Ordovician beds of Siberia and the USA. Here, we report a new genus, *Cabaneroceras* n. gen., and a new species of *C. aznari* n. sp. from Middle Ordovician strata of central Spain. This finding widens the paleogeographic range of the order toward high-paleolatitudinal areas of peri-Gondwana. A curved conch, characteristic for the new genus, was previously unknown from members of the Intejocerida.

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Introduction

Intejocerids are a unique group of cephalopods, previously known only from Siberia (Balashov 1960, 1962, 1968) and North America (Flower, 1964, 1968; VanCamp Gil, 1988). The most conspicuous characters of intejocerids are their long septal necks, and their large siphuncles, which are filled with heavy lamellar deposits and which form a coral-like radial pattern in cross section. Like other cephalopods with long septal necks and heavy endosiphuncular deposits, intejocerids were relatively large for their time with conch diameters reaching more than 100 mm. The isolated, several decimeter long steinkerns of the specimens described herein occur exclusively and in relative high abundance at a single locality in the northern Ciudad Real province where they are found as the weathered residue of the soft mudstone of the Navas de Estena Formation. The steinkerns are often superficially eroded and parts of the phragmocone, such as septa and outer shell are not preserved. This obstructed the correct identification of these remains as cephalopods, which were originally interpreted as remains of hexactinellid dictyospongids (Gutiérrez-Marco et al., 2013, p. 596, fig. 4c, 2015a, p. 130, fig. 20A). Here, we identify and describe these fossils for the first time in detail.

Geological setting

The examined material comes from three nearby localities in the central part of the Mounts of Toledo area, central Spain, two of them situated within the Cabañeros National Park (‘Los Medianiles’ and ‘Navaldelchorro’, see Gutiérrez-Marco et al., 2013, 2015a) and the third immediately adjacent to same (‘Cuesta de Valderuelo’ section, see Reyes-Abril et al., 2010;

Gutiérrez-Marco and Sá, 2017) (Fig.1). This area belongs to the southern part of the Central Iberian Zone of the Iberian Massif, where large outcrops of Paleozoic fossiliferous rocks have been known since the middle half of the XIX century, including early reports and illustrations of Middle Ordovician cephalopods both from the Portuguese (Sharpe, 1849) and Spanish parts (Verneuil and Barrande, 1855).

All studied specimens come from a relatively narrow (5–45 m) stratigraphic interval of fossiliferous mudstones located at the lower third of the Navas de Estena Formation. The formation is a thick (up to 800 m) Darriwilian succession of massive dark mudstones and siltstones, partly with noduliferous horizons. The Navas de Estena Formation (Fm) stratigraphically overlies the Lower Ordovician sandstone group comprising the Armorican Quartzite (Floian age) and the transitional Marjaliza beds (Floian–Dapingian ages).

From north to south, the fossiliferous localities in the Navas de Estena Fm are as follows:

Locality 'Navaldelchorro'.—About 10,000 m to the south of Los Navalucillos (province of Toledo), east of Posturero' house on the left bank of the La Calanchera stream (lat. 39º 34' 28" N, long. 4º 39' 13. 7" W). From this locality (Fig. 1.2a) came a single limonitic siphuncle (MGM-8196O), from mudstone beds c. 100 m above the base of the Navas de Estena Formation.

Locality 'Cuesta de Valderuelo'.—Located c. 5,600 m to the SE from Navas de Estena, province of Ciudad Real (lat. 39º 27' 33" N, long. 4º 28' 31" W). This locality corresponds to the bed NE-IIIA of the section (Reyes-Abril et al., 2010), from which some brachiopods (Reyes-Abril et al., 2010) and ichnofossils (Gutiérrez-Marco and Sá, 2017) were described and illustrated. The locality (Fig. 1.2b) is about 120–135 m above the base of the Navas de Estena Formation, in the southwestern flank of the Navas de Estena syncline. A single siphuncle preserved in shale was found at Cuesta de Valderuelo (MGM-8197O).

Locality 'Los Medianiles'.—About 8,700 m to the ENE of Horcajo de los Montes, province of Ciudad Real, in the northern bank of the La Chorrera stream south of Sierra de Valdefuertes (lat. 39º 21' 42,2" N, long. 4º 33' 41" W). From this locality (Fig. 1.2c) we have recovered about 90 fragments of isolated steinkerns of intejocerid siphuncles. Only few specimens of this collection occurred strictly *in situ*, ca. 80–85 m above the base of the Navas de Estena Formation. The majority of specimens have been collected on a labor field which gently dips south from the narrow outcropping area in the northern flank of La Chorrera Syncline.

All three localities contain an assemblage of trilobites, brachiopods, mollusks, ostracods and echinoderms, detailed by Gutiérrez-Marco et al. (2013, 2015a) for assemblages from Cabañeros National Park (see also: Reyes-Abril et al. 2010; Gutiérrez-Marco and Sá, 2017) for the Cuesta de Valderuelo section. The occurrence of the graptolite *Didymograptus artus* Elles et Wood, plus some trilobites and brachiopods of regional biochronological significance indicate an early Oretanian age to the assemblage according with the Bohemo-Iberian regional scale (Gutiérrez-Marco et al., 2015b, 2017), equivalent to an early mid Darriwilian age at the global chronostratigraphy (Bergström et al., 2009).

Materials

The available material consists of isolated steinkerns of siphuncles, partly with impressions of septal necks as moulds within the sediment. The steinkerns consist of massive limonite and limonitic mudstone. No original calcareous material is preserved. Preserved parts of septa and septal necks are silicified. Internal characters of the siphuncles can be traced along pattern of differences in the compactness of the limonite. The cross-sections of the specimens are often slightly diagenetically deformed, which is indicated by the similarly deformed endosiphuncular lamellae. Imprints of bryozoan epizoans occur on the silicified shelly surface of the septal necks and on the surface of the steinkern itself (Figs 2.8, 3.2) (specimen MGM-8181O).

Repositories and institutional abbreviations.—The material described herein is deposited at the Museo Geominero of Madrid (prefixed numbers MGM) which belongs to the Instituto Geológico y Minero de España / IGME (Spanish Geological Survey).

Systematic paleontology

Order Intejocerida Balashov, 1960

Family Padunoceratidae Balashov, 1960

Genus *Cabaneroceras* new genus

Type species.—*Cabaneroceras aznari* n. sp., by monotypy.

Diagnosis.—As for the type species by monotypy.

Occurrence.—Mounts of Toledo, Navas de Estena Formation, central Spain.

Etymology.—The name refers to the Cabañeros National Park in Spain. All currently known specimens of this genus are from this territory or its immediate surroundings (Valderuelo section).

Remarks.—The placement of the new genus within the Padunoceratidae is justified by the occurrence of branching, irregularly shaped lamellar endosiphuncular deposits and the holochoanitic septal necks. *Cabaneroceras* n. gen. differs from other Intejocerids in having a curved conch, a relatively large angle of expansion and relatively shallow concave siphuncular segments. The endosiphuncular lamellae of *Cabaneroceras* n. gen. are relatively widely spaced, similar to *Evencoceras*, from which they differ in forming an irregularly spaced ventral endosiphotube.

Cabaneroceras aznari new species

Figures 2–4,

Holotype.—MGM-8183O (Figs 2.1, 2.5, 2.6, 4.4), Navas de Estena Formation, about 100 m above the base. Lower mid Darriwilian, *Didymograptus artus* graptolite zone, 'Los Medianiles' site in the northern flank of the La Chorrera syncline, northeast of Horcajo de los Montes, province of Ciudad Real, central Spain.

Diagnosis.— Slightly curved brevicones with marginal siphuncle. Siphuncle at concave margin of conch curvature with slightly compressed or circular cross-section with angle of expansion of

c. 8–12°. Ventral margin of siphuncle slightly flattened. Siphuncle diameter c. three to four times that of septal distance. Siphuncular segments slightly concave. Septal necks holochoanitic. Endosiphuncular deposits longitudinally subdivided into c. 25 irregularly spaced radially arranged lamellae separated by narrow, folded blades as interspaces. Lamellae laterally downcurved toward the ventral side forming an endosiphuncular tube with an irregularly compressed semicircular shape in cross section at ventral side of siphuncle.

Occurrence.—As for genus, by monotypy.

Description.—The holotype is a fragment of a siphuncle, slightly diagenetically laterally compressed with a dorso-ventral diameter of 46–73 mm, a width of 38–60 mm at a length of 135 mm, expanding with an angle of 11.5° dorso-ventrally. The siphuncle is slightly curved with the ventral side less curved than the dorsal side. Traces of the septa and septal necks are visible on the steinkern only on the dorsal side of the holotype indicating a slightly concave shape of the siphuncular segments and an at least holochoanitic length of the septal necks that ranges over the entire height of chamber. The former position of the septa is visible around the surface of the holotype as rounded ridges. These ridges are oblique toward the growth axis with an angle that is c. 20° from the angle perpendicular to the growth axis and slopes toward the dorsal (antisiphuncular) side of the conch. In places where the steinkern exposes the inner surface of siphuncular deposits (which is the outer surface of the siphuncle), a number of c. 25 lamellae are visible as broad bands divided by thin (<1 mm) longitudinal grooves. In cross-section, these lamellae are visible, reaching into a depth of up to 20 mm of the siphuncle, where they are radially arranged and irregularly folded leaving a central space or tube filled with massive limonite. The central tube is eccentrically positioned within the siphuncle with a ventral contact to the siphuncular wall and irregularly compressed, with semicircular cross-section.

Specimen MGM-8184O (Fig. 2.4) is a part of a steinkern of a siphuncle with a maximum diameter of 71 mm; it has a slightly compressed cross section with particularly well preserved holochoanitic septal necks; at its ventral side it is in a contact to the outer shell, which in its best-preserved parts smooth. Details of potential ornamentation are probably not visible due to preservation.

Etymology.—The name was given in honour of Alejandro Aznar, the owner of the private property of the type locality, supporter of the 11th International Symposium on the Ordovician System, Spain, 2011 and producer of the fine Rioja wine "Marqués de Riscal".

Materials.— Seventeen paratype specimens (MGM-8180O – MGM-8189O, MGM-8191O – MGM-8195O, MGM-8198O, and MGM-8199O) were available for closer examination. Fourteen additional, less valuable or more incomplete specimens, were deposited in the same collection MGM-8196O – MGM-8197O, MGM-8200O – MGM-8206O, and MGM-8225O – MGM-8230O.

Remarks.—The material of *Cabaneroceras aznari* n. sp., described above, consists exclusively of fragments of siphuncles. Many of the specimens are also diagenetically slightly deformed. This fragmentary preservation constraints the diagnosis of this new species to the preserved internal characters. However, the erection of a new species and genus is justified, because the known internal features are unique (see discussion of *Cabaneroceras* n. gen.) and unknown in this combination from any other padunoceratid cephalopod.

Discussion

Little can be said about the taphonomy and depositional history of the material. The now limonitic mineralogy of the steinkerns probably represents a primary deposition and burying under deoxidized conditions with pyrite (FeS) as replacement of organic rich spaces, and later oxidation and dissolution of the calcareous deposits. Alternatively, massive pyrite may have preferentially replaced the shelly material rich in in organics (e.g. nacre), while carbonate poor in organics may be have been replaced by crystalline pyrite (pers. comm. D. Evans). The local presence of bryozoan epizoans, which covered parts of already broken septa and outer surfaces of the septal necks is evidence of a relatively complex depositional history with potential secondary reworking.

The massive limonitic parts of the siphuncles are interpreted by us as originally organic rich shelly material, and in contrast, the less massive, more porous limonitic spaces are interpreted as representing areas originally filled with porous calcareous endosiphuncular deposits. This results in a reconstruction of a pattern with a number of radially arranged lamellae and elongated endoconic cells or compartments that where divided by folded interspaces or endosiphoblades (sensu Flower, 1964, see Fig. 4), a reconstruction which is consistent with siphuncular features of better-preserved material of intejocerids, specifically with *Evencoceras* Balashov, 1960 (Balashov, 1960, pl. 28, fig 1; VanCamp, Gil 1988, fig. 14. 6). The siphuncles described herein differ from all other known intejocerids in having a wider angle of expansion, and in being slightly curved, which justifies the erection of a new genus and probably would be adequate to suggest a new family if more complete material would be available.

Conclusions

Our interpretation and systematic classification of the cephalopod siphuncles collected from the Navas de Estena Formation has two main consequences: (1) The known paleogeographic range of the Intejocerida now widens from restricted to low paleolatitude Siberia and Laurentia toward high latitude peri-Gondwana; (2) the known morphological diversity of the Intejocerida widens significantly from originally restricted to slender orthoconic forms, to now also including slightly curved brevicones. Notably, distinct groups of curved brevicones are known also from other predominantly hemi-holochoantic higher cephalopod taxa, such as the Piloceratidae of the Bisonocerida (comp. Evans and King 2012) and Cyrtendoceratidae of the Endocerida (Teichert 1964).

The intejocerids reported herein also add to the known diversity of Ordovician cephalopods from the Iberian Peninsula. Currently, this incudes member of the Ascoceridae, Ellesmerocerida, Endocerida, Orthocerida, Lituitida, and Tarphycerida (see: Babin and Gutiérrez-Marco, 1992; Sá and Gutiérrez-Marco, 2009 for previous compilation). With the exception of two tarphycerid species, most of the previously published taxa are based on poorly preserved material occurring as incomplete moulds and casts in siliceous mudstones and sandstones. The absence of critical internal structures in many of these specimens does not allow for a taxonomic identification at genus or species level and many taxa are in need of a revision. Hopefully, the recent reappraisal of early Paleozoic peri-Gondwanan cephalopod faunas from elsewhere (e. g. Kröger et al., 2012;

Evans et al., 2013, 2015; Bogolepova et al., 2014; Niko and Sone, 2014, 2015; Aubrechtová, 2015; Cichowolski et al., 2015, 2018; Ghavidel-Syooki et al., 2015; Rolet and Plusquellec, 2016; Aubrechtová and Turek, 2018; Manda and Turek, 2018; Ebbestad et al., 2019; Fang et al., 2019) will stimulate future research on the Iberian cephalopods.

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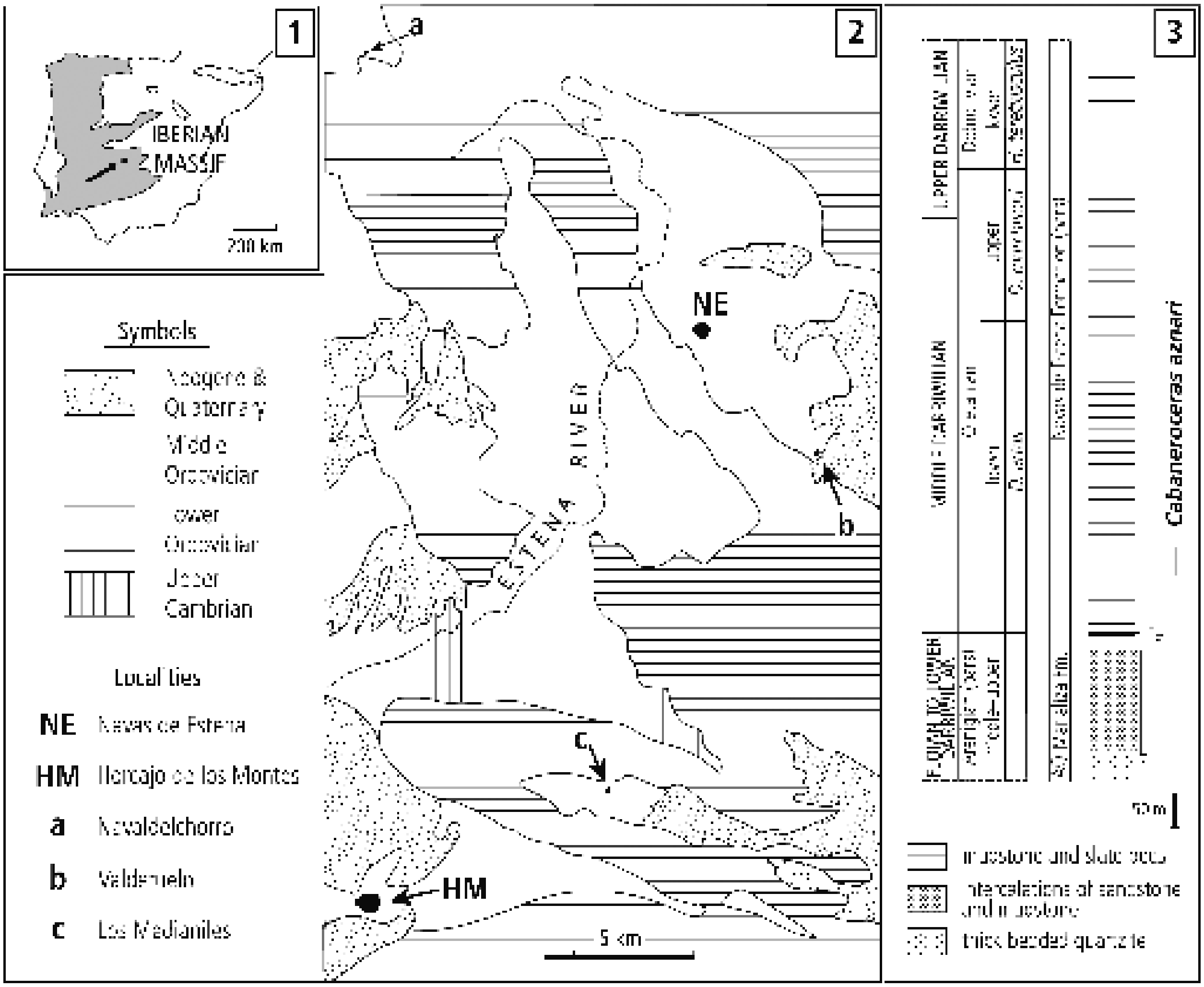
Figures and Figure Captions

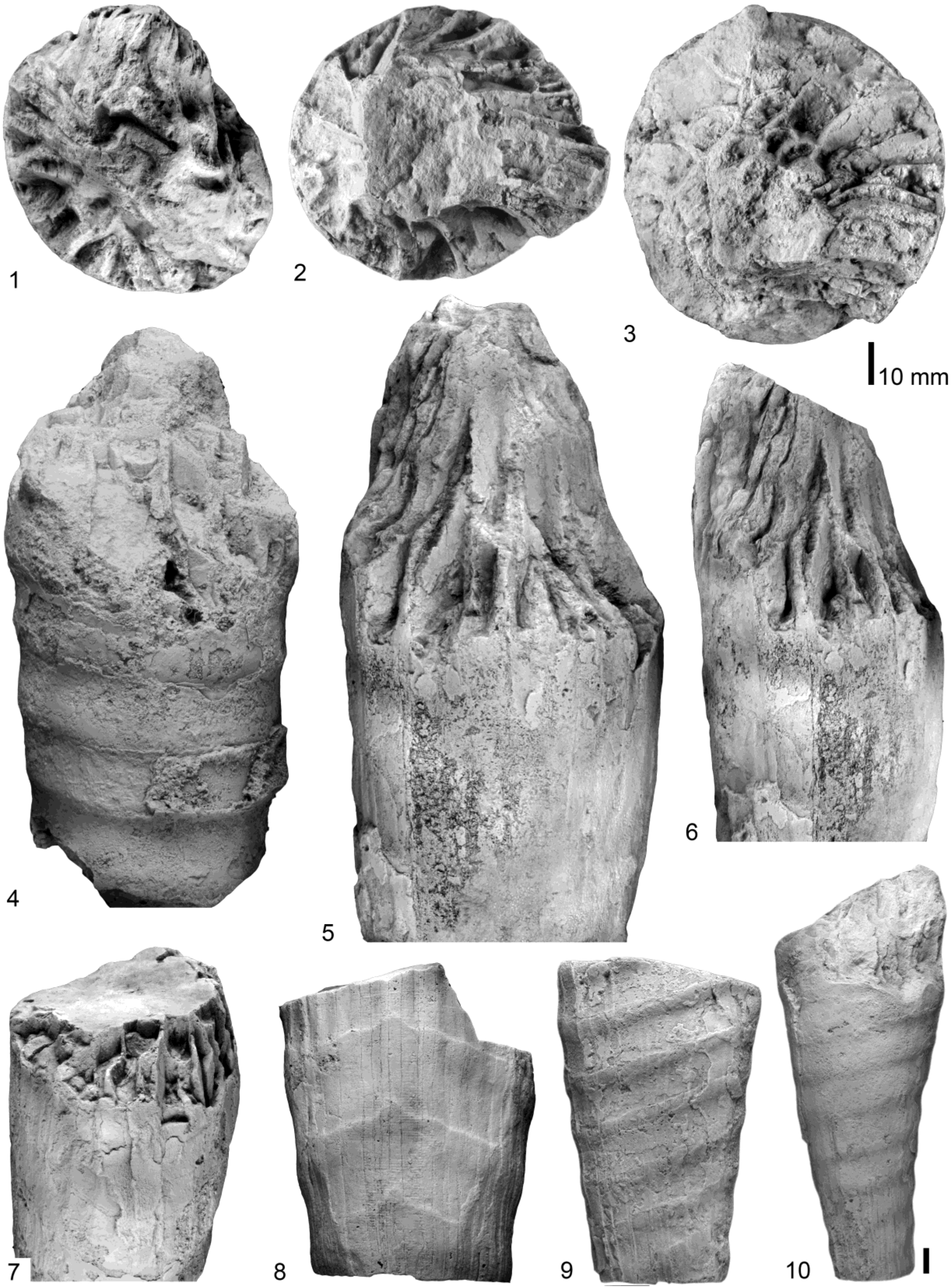
Figure 1. Details of fossil localities and stratigraphy of the occurrences of *Cabaneroceras aznari* n. sp., Middle Ordovician, central Spain. (**1**) General location of the studied area in the Iberian Peninsula (arrowed). Grey area corresponds to the Neoproterozoic basement and Paleozoic rocks affected by the Variscan Orogeny (Iberian Massif). (**2**) Geological sketch map of a part of the central Mounts of Toledo region showing the position of the localities yielding *Cabaneroceras aznari* n. gen , n. sp. (type locality in c). (**3**) Stratigraphic log of a part of the Navas de Estena Formation with the range of the new taxon.

Figure 2. Siphuncular fragments of *Cabaneroceras aznari* n. sp., from Navas de Estena Formation, Middle Ordovician, central Spain: **(1)** holotype, MGM-8183O, adapical view. **(2)** specimen MGM-8182O, adapical view. **(3)** specimen MGM-8184O, adapical view. **(4)** specimen MGM-8184O, dorsal view. **(5)** holotype, ventral view. **(6)** holotype, lateral view. **(7)** MGM-8186O, lateral view. **(8)** specimen MGM-8181O, ventral view, note horizontal traces of bryozoan overgrowth **(**see details in Fig. 2b). **(9)** specimen MGM-8198O, lateral view. **(10)** specimen MGM-8187O, lateral view. Scale bars = 10 mm, for specimens **1**–**8** and **9** –**10**, respectively. All the specimens where whitened with MgO before photography.

Figure. 3. Details of siphuncular fragments of *Cabaneroceras aznari* n. sp., from Navas de Estena Formation, Middle Ordovician, central Spain. **(1)** Longitudinal cross section of steinkern of siphuncular fragment of *Cabaneroceras aznari* n. sp., specimen MGM-8199O. Dark area is massive limonite and probably originally was calcareous endosiphuncular deposit. **(2)** Detail of traces of bryozoan epizoans on specimen MGM-8181O (marked with arrow). Scale bars = 10 mm. Specimen in **2** was whitened with MgO before photography.

Figure 4. Camera lucida drawings of cross section view of siphuncle steinkerns of *Cabaneroceras aznari* n. sp. from Navas de Estena Formation, Middle Ordovician, central Spain. The radial structures are interpreted here as either interspaces between folded siphuncles, or as endosiphoblades (sensu Flower, 1964). All figured specimens are arranged in a position with assumed ventral side down. Note the different orientation and grade of diagenetic compression, which reflects the original position in the sediment: **(1)** specimen MGM-8188O. **(2)** specimen MGM-8189O. **(3)** specimen MGM-8182O. **(4)** holotype, specimen MGM-8183O. **(5)** Specimen MGM-8180O. Scale bar = 10 mm.


1
IBERIAN
MASSIF
200 km
2
a
NE
b
c
HM
RIVER
ESTENA
5 km
Symbols
Neogene &
Quaternary
Middle
Ordovician
Lower
Ordovician
Upper
Cambrian
Localities
NE Navas de Estena
HM Horcajo de los Montes
a Navaldelchorro
b Valdehuelo
c Los Medianiles
3
UPPER DARRIWILIAN
MIDDLE DARRIWILIAN
Cabaneroceras aznari
50 m
mudstone and slate beds
intercalations of sandstone and mudstone
thick bedded quartzite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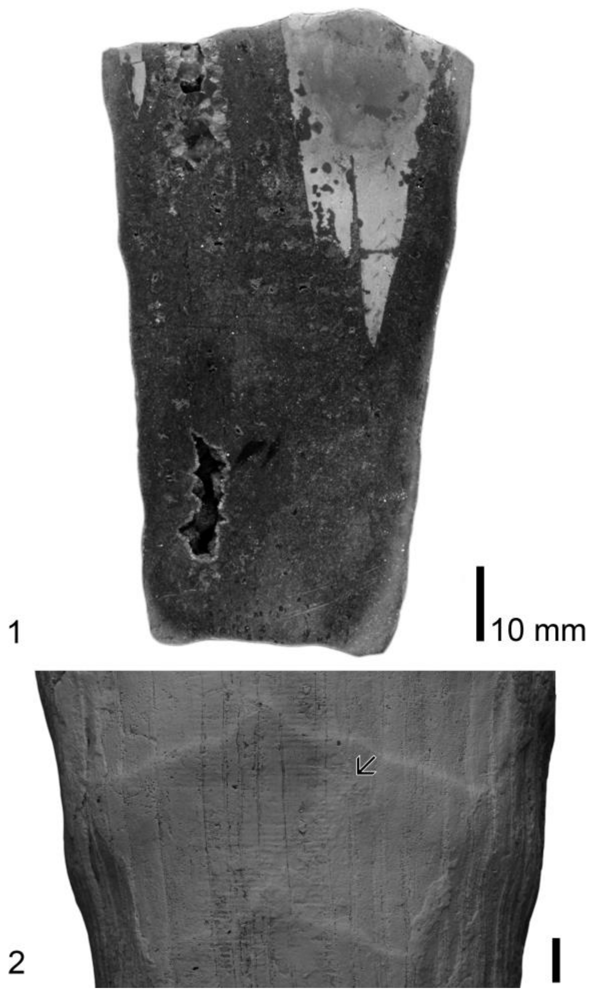
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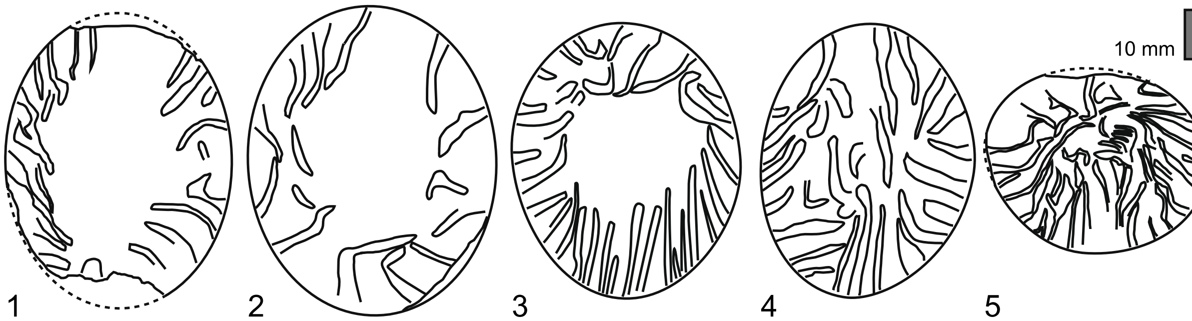
10 mm
1
2
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5